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Evaluation of MDF bonding with polyurethane of castor oil

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Abstract

Adhesives used to bond the wood panels are petroleum-based and has volatile organic compound, VOCs. Harmful substance when inhaled by human being and can cause different problems, such as cancer. As an alternative to replace these adhesives is to use the polyurethane derived from castor oil (PU), a renewable resource that can be used to structural applications, indoor and outdoor environments. It is weather resistant and has good mechanics properties. The aim of this paper is to evaluate the mechanical resistance of glued joint with PU biding MDF panels. It was produced raw MDF samples glued two by two with 0.05 g of adhesive in 1 cm^2. Where 6 samples were used with PVA adhesive, 6 with contact adhesive and 6 with PU. After 72 h it was applied a mechanical analysis technique of shear bond strength, according to the standards ASTM D 3983-93 and ASTM D897-95A. The results shows the shear average resistance of PU was 12.67 ± 2.26 MPa, whereas for the PVA adhesive was 2.55 ± 0.19 MPa and the contact adhesive was 3.26 ± 0.63 MPa. It is conclusive the polyurethane derived from castor oil can be used to bind MDF panels, due to its superior shear average resistance compared to PVA and contact adhesives.

Keywords: MDF, Polyurethane, Castor oil, Bind

Background

More than 70 % of wood derivative products use some kind of adhesive, with the increased replacement of wood products by its derivatives generated an increase of synthetic adhesives consume [1].

Normally, the panels binding process to produce furniture is made with thermosetting resins, such as urea-, phenol-, or melamine-formaldehyde and isocyanate [2]. These resins comes from petroleum and has solvent in its compositions, as volatile organic compound, VOC's, toxic, carcinogenic and mutagenic substances [3].

Among the synthetics adhesives, the most used by Brazilian's wood and furniture industry, stand out poly (vinyl acetate) adhesives, PVA, besides the polyurethane ones [1]. The furniture industries use contact adhesives that may provide to its workers leukemia and nasal cancer development risk, apart from instant abortion on women case [4].

These adhesive solvents can be skin absorbed and make it infections susceptible. Also can cause irritations and allergic reaction on sensitive people. When inhaled can cause

headaches, fatigues, nausea, eyes irritations and in its respiratory systems or mental and visual disorders [5].

The polyurethane derived from castor oil is extract from *Ricinus communis* and do not have VOC's in its composition [6]. The castor bean (*R. communis*) is a tropical plant with great oleo chemical potential that can provide polyols from its fatty acids [7]. The castor bean seed's most important constituent is ricinoleic acid, which also is the castor oil biggest component. The hydroxyl groups provide alcohol characteristics to the oil that are relatively stable under different pressure and temperature conditions [8]. Polyurethane can be used in structural applications, as well as indoor and outdoor environments and is weather resistant [9].

Azevedo et al. [10] did a thermo-mechanical characterization polyurethane derived from castor oil by instrumented nanoindentation test and ones concluded that the Berkovich pyramidal tip hardness was 0.14 GPa. The modulus of elasticity, with spherical tip, was 2.4 GPa, using Hertz methodology. The viscosity, also measured by spherical tip, was $(22 \pm 2) \times 10^{12}$ Pa s. The temperature of initial mass loss was 250 °C and the glass transition temperature was 76 °C.

Campos and Lahr [11] studied MDF panels, with Eucalyptus and Pinus fibers, resistances properties with 8, 10 and 12 % of urea-formaldehyde, polyurethane derived from castor oil bi-component and inorganic resin. The Eucalyptus and Pinus panels with 12 % of PU obtained the best results for both internal adhesion (0.91 and 0.89 MPa) and flexion resistance (29.4 and 28 MPa).

Fiorelli et al. [12] developed sugarcane bagasse panels with polyurethane derived from castor oil and investigated its physical and mechanical characteristics. The results indicate a high-density material and suitable for industrial use.

Silvia et al. [13] evaluated, with European standard EMB/IS-2: 1995 support, the mechanical properties of Pinus fibers panels with polyurethane derived from castor oil (PU) and concluded that with 6 % of PU proportion provided mechanical properties compatible to the standard requirements.

Campos et al. [14] evaluated MDF panels of *Pinus caribaea* var. *hondurensis* fibers with polyurethane derived from castor oil, according to the European standards. Its physics and mechanics properties showed superior values than standard's established. With 731 kg/m^3, 12 % of thickness swelling and 30.7 % of water absorption, 2754 MPa for MOE and 27.2 MPa for MOR, the internal adhesion was 0.79 MPa. Indicating the adhesive is promising in MDF production.

Substrate adhesion is a physic-chemical phenomenon that provides a tension transfer mechanism between two pieces by molecular process and involves both mechanicals theories of polymer diffusion and chemical adhesion [15]. In these models, a good adhesion requires a good substrate's surface wettability by the adhesive as well as its penetration on the surface pores. Its solidification and its flexibility are also required to reduce the tension effects caused by exertion [16].

The tendency to replace formaldehyde-based adhesives due to its harmful effects in both environment and human health, led the efforts in ecofriendly adhesives research. As PVA, the polyurethane derived from castor oil showed satisfactory results on fiber composites [17] and plywood manufactory [3]. Researches between MDF and polyurethane derived from castor oil interaction are scant, generating a need to study its

properties. The aim of this paper is to evaluate the mechanical resistance of glued joint with polyurethane derived from castor oil in MDF panels.

Experimental

It was used the raw MDF panel with 0.70 g/cm^3 of density and 10 mm of thickness.

The PVA Cascola® Cascorez Extra is PVA-based adhesive, indicated for wooden artifact collage. This adhesive uses the conventional bonding process, once the processes finish within 3–4 h in room temperature.

The contact Cascola® Extra, according to its manufacturer, is a fast drying adhesive, provides a good finish and high performance [18]. The manufacturer does not provide its technical information.

The polyurethane derived from castor oil was a donated by Cequil Central de Ind. Des. Polímeros de Araraquara-SP is a bi-component of polyurethane resin that acts chemically with wood resin. It is not toxic and is compatible with any kind of wood and its finishing [19]. It has no mineral filler (zero solids content), density of 0.99 g/cm^3, 500 cps in 25 °C of viscosity, total cure time of 72 h and Shore D hardness of 60.

Samples

There were cut 36 pieces from MDF panels, Fig. 1a, in L shapes to adapt to the machine claw. Then, to provide a smooth surface, they were manually sanded with emery paper 220 grit. Then, the adhesive area was marked with a pen, according to the standards ASTM D 3983-93 [20] and ASTM D 897-95A [21], as shown by Fig. 1c.

In the demarked area were added 0.05 g of adhesive in 1 cm^2 (500 g/m^2) in 6 samples for each adhesive, pressing manually about 1 min against another sample provided with

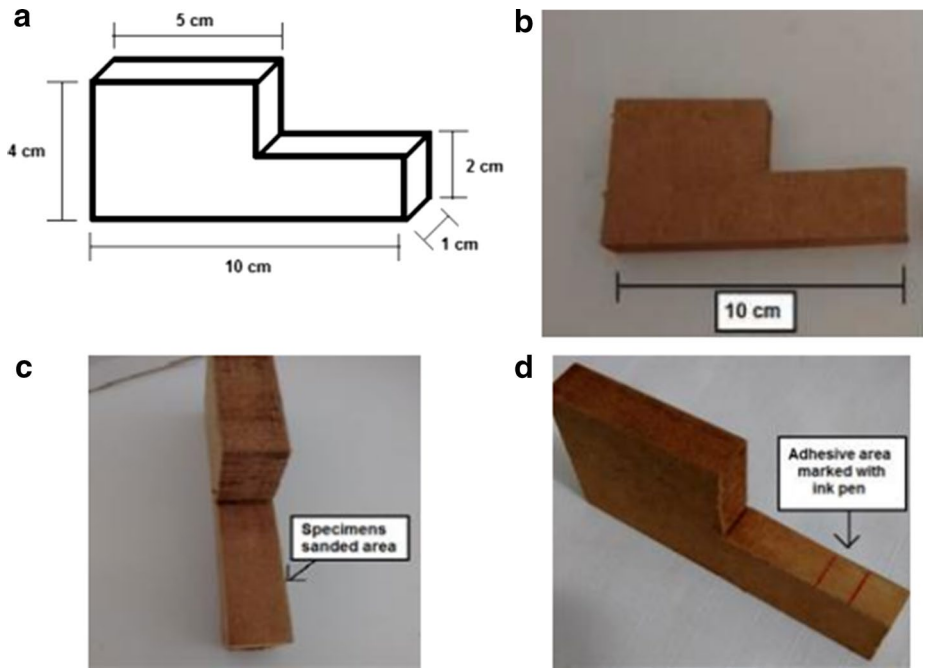

Fig. 1 Samples for shear test; **a** samples measures, **b** sample cut, **c** sample area sanded, **d** adhesive area marked with *pen*

no adhesive, following the manufacturer orientations. The PU manufacturer suggests polyol/pre-polymer proportions of 1:1. After the mixture, the PU was put into a desiccator coupled with pump for 7 min to remove the air bubbles [19]. The contact adhesive has to be first spread and then wait for 5 min to bind the other piece. PVA adhesive did not require any specific care [18].

After the pressure, it formed 18 samples set in total, which were left at rest for 72 h in an environment with controlled relative humidity to 50 % and 25 °C to complete the adhesive drying, Fig. 2. Then, a mechanical analysis technique of shear bond strength was applied.

The shear test was applied according the standards ASTM D 3983-93 [20] and ASTM D 897-95A [21], on an universal test machine, EMIC DL10000, with 500 Kgf of load 2 mm/min speed.

Results and discussion

Figure 3 shows stress–strain curves obtained byshear test.

It can be observed at Fig. 3 the maximum tension obtained by PVA glued joint was 1.5 MPa with 2.5 mm deformation. The contact adhesive presented 3 MPa and 5.5 mm deformation. The polyurethane, on the other hand, showed 13.8 MPa and deformation of 7.8 mm.

Fig. 2 One set during its rest time

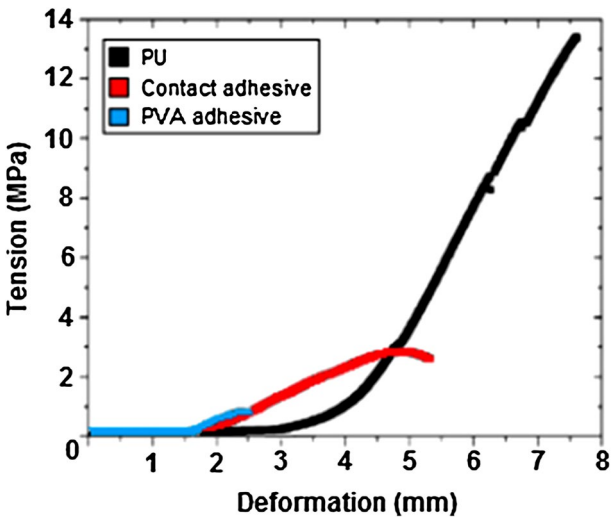

Fig. 3 Stress–strain curves obtained by shear test

The polyurethane's rupture tensile was superior when compared to others two adhesives, demonstrating its better resistance. Phenol-formaldehyde based adhesives are structural type ones and can be used on outdoor environments. Urea-formaldehyde ones are also structural types but only can be used on indoor environments. On the other hand, polyurethanes are considered a semi-structural adhesive [22] which has limited applications due to its low water resistance when compared to structural ones. Even being a semi-structural adhesive, the polyurethane has better performance than structural ones with external applications.

Figure 4 represent the results obtained by shear test. It can be observed that the PU shear strength is superior to the others adhesive. This can be attributed to polyurethane's strong interaction between free OH and NCO groups, that will promote a chemical adhesion among MDF and PU. Merlini et al. [17] claims that this mechanism is responsible for natural fibers surfaces and PU adhesiveness and compatibility.

The shear strength obtained by MDF with polyurethane are superior than others adhesives. Campos et al. [23] tested PVA utilization on *Eucalyptus* sp. and *Pinus* sp. plywood production, with 10 min pressing time and 90 °C. It was found 3.76 MPa for glued joint shear strength.

Campos et al. [24] found, for *Pinus* sp. plywood panels with polyurethane derived from castor oil with 400 g/m^2 g weight, under 1.5 MPa of pressure, 60 °C for 15 min, statics flexion results for MOR and MOE values 39–56 and 10,000–15,322 MPa, respectively.

A higher wood density may influence veneers adhesive bonds, due to a higher difficulty of adhesive penetration and can create a higher internal steam pressure during the hot pressing. This contributes to reduce the resin-polymerizing rate [9].

The results obtained in this paper approach to its values, being that variations may occur depending the wood species, its gram weight, adhesive type, as well as the environmental conditions to produce the plywood panels. However, it was not found any MDF panels with polyurethane derived from castor oil panel papers to compare the results.

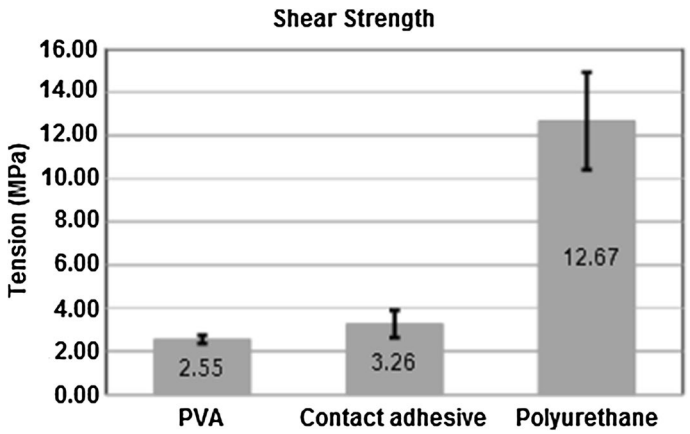

Fig. 4 Average shear strength result for PVA, contact adhesive and polyurethane

Conclusion

The results found in this paper show a superior shear strength in MDF with PU samples than PVA and contact adhesives, most commercially used.

Petroleum based adhesives such as PVA and contact adhesive may cause damage to human health and do not come from a renewable resource. This goes against the three sustainability pillars: economically viable, socially fair and ecologically friendly practices. The replacement by furniture industry to green ones is viable, especially because show better bond resistance when compared to traditional adhesives.

With these positives results it may be possible to do deeper studies in this adhesive, such as evaluate the resistance with boiling, dry, cycle and cold water treatments. Also, study its best pressing time, grammar weight and pre-polymer/polyol proportion.

Authors' contributions

CRP, REM, FHS and GSC participated in performing the experiments and writing of the manuscript, ECA and SCN conceived the study, participating in its design and coordination, helping to drafting the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Liability of note

The authors are solely responsible for what is contained in this work.

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